



Polymetallic Sulphides

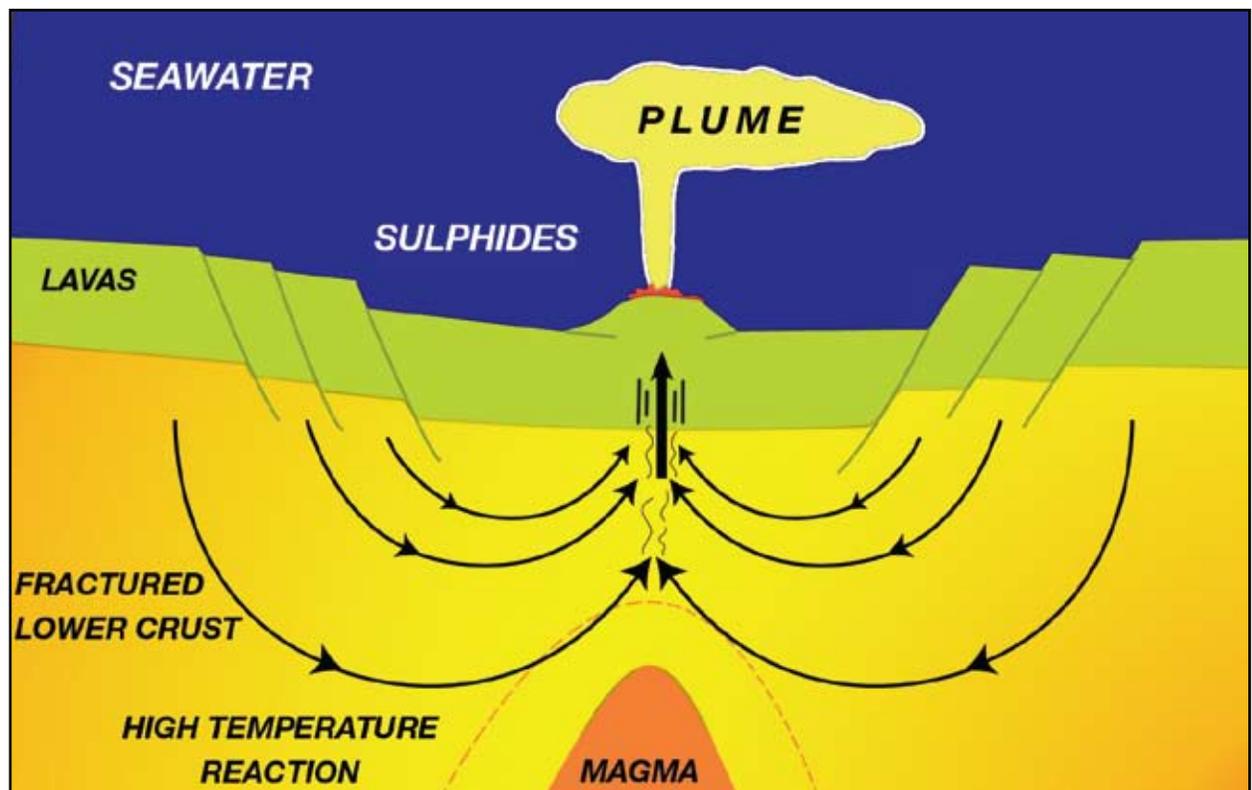
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Discovery and Formation

In 1979, on the East Pacific Rise at 21 degrees north latitude off Baja California (Mexico), scientists exploring the ocean floor discovered chimney-like formations of dark rock atop sulphide mounds, spewing hot water and surrounded by animal species different from any previously known. Since then, studies have shown that these black-smoker complexes are an outgrowth of the formation of new oceanic crust through seafloor spreading as the tectonic plates underlying the earth's surface converge or move apart. Moreover, this activity is intimately associated with the generation of metallic mineral deposits at the seafloor.

At water depths up to 3,700 metres, hydrothermal fluids, having seeped from the ocean into subterranean chambers where they are heated by the molten rock (magma) beneath the crust, are

discharged from the black smokers at temperatures up to 400° Celsius. As these fluids mix with the cold surrounding seawater, metal sulphides in the water are precipitated onto the chimneys and nearby seabed. These sulphides, including galena (lead), sphalerite (zinc) and chalcocite (copper), accumulate at and just below the seafloor, where they form massive deposits that can range from several thousands to about 100 million tonnes. High concentrations of base metals (copper, zinc, lead) and especially precious metals (gold, silver) in some of these massive sulphide deposits have recently attracted the interest of the international mining industry. Many polymetallic sulphide deposits are also found at sites that are no longer volcanically active.



Formation of seafloor sulphides. (Herzig et al. Proceedings. Minerals other than polymetallic nodules of the international seabed area, Kingston, Jamaica: International Seabed Authority, 2000, pp. 109-161.)



Distribution

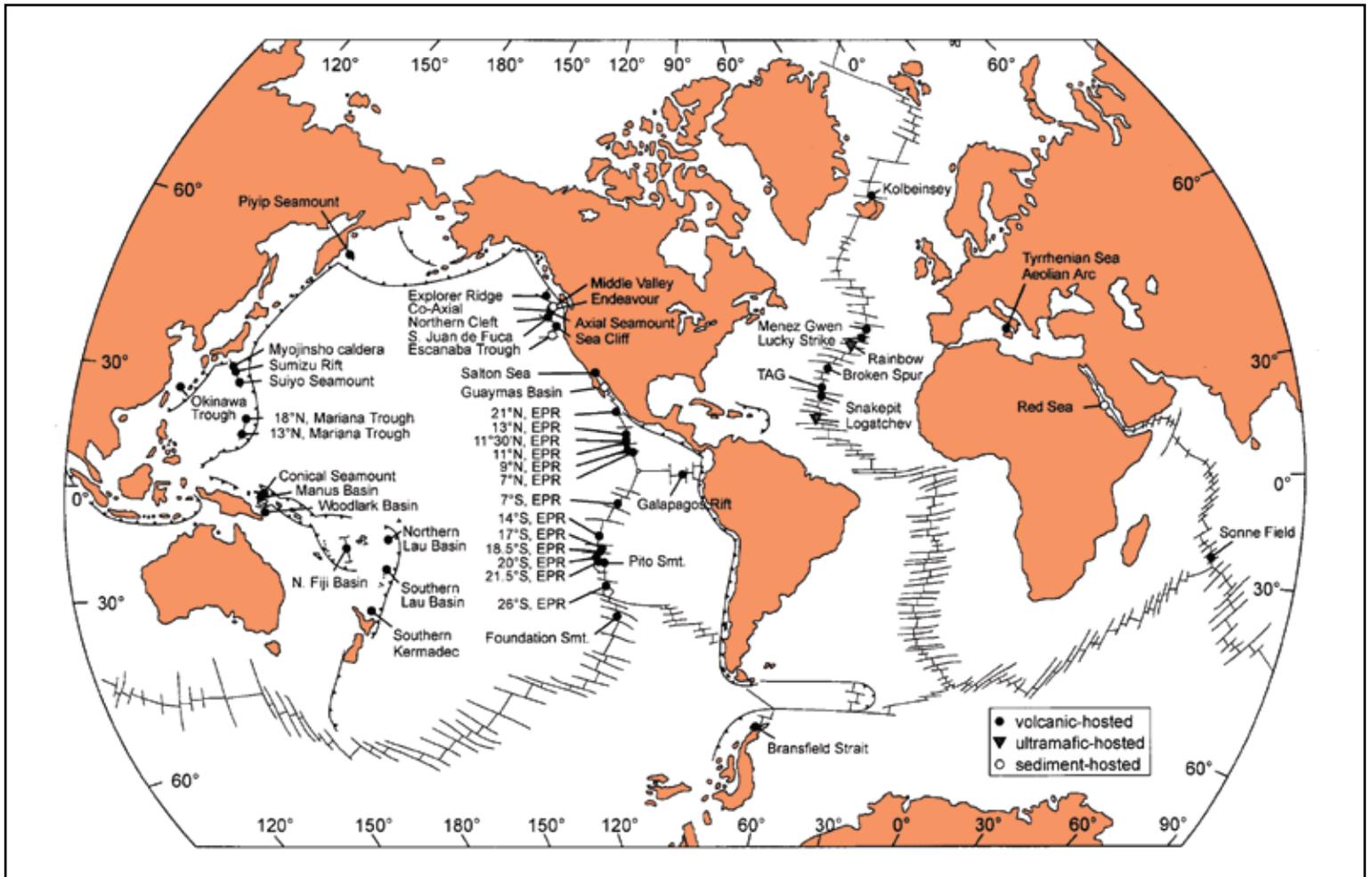
Most sites have been located in mid-ocean at the East Pacific Rise, the Southeast Pacific Rise and the Northeast Pacific Rise. Several deposits are also known at the Mid-Atlantic Ridge but only one has so far been located at the ridge system of the Indian Ocean. The paucity of known sulphide deposits at the Mid-Atlantic Ridge and the Central Indian Ridge is largely explained by the fact that exploration in these areas has been limited. Only some 5 percent of the 60,000 kilometres of oceanic ridges worldwide have been surveyed in any detail.



In the mid-1980s, additional sulphide deposits were discovered in the southwestern Pacific, at ocean margins where basins and ridges occur on the seafloor between the continent and volcanic island arcs. In these so-called back-arc spreading centres, magma rises close to the surface at convergent plate margins where one tectonic plate slips beneath another in a process called subduction. These discoveries led to extensive exploration of the marginal basins and the arc and back-arc systems of the western and southwestern Pacific, resulting in the discovery of further deposits in the Lau Basin and North Fiji Basin east of Australia, and the Okinawa Trough southwest of Japan. In 1991, extensive sulphide deposits were found to be associated with felsic volcanism -- the most explosive type of volcanic activity, producing the heaviest ash flows -- in places such as the Manus Basin, north of New Caledonia. Hydrothermal deposits have also been located in the nearby Woodlark Basin, where seafloor spreading propagates into the continental crust east of Papua New Guinea. Today, more than 100 sites of hydrothermal mineralization are known, including at least 25 sites with high-temperature black-smoker venting.



Examples of hydrothermal chimneys and mounds. Photos courtesy of NOAA



Location of hydrothermal systems and polymetallic sulphide deposits at the modern seafloor

(Herzig et al. Proceedings. Minerals other than polymetallic nodules of the international seabed area, Kingston, Jamaica: International Seabed Authority, 2000, pp. 109-161.)

Metal Content



Massive sulphide ore (Peter Herzig)

Comparison of nearly 1,300 chemical analyses of seafloor sulphides reveals that deposits in different volcanic and tectonic settings have different concentrations of metals. Relative to samples from sediment-starved mid-ocean ridges, massive sulphides formed in basaltic to andesitic environments of back-arc spreading centres (573 samples) are characterized by high average concentrations of zinc (17%), lead (0.4%) and barium (13%), but little iron. Polymetallic sulphides at back-arc rifts in continental crust (40 samples) also have low iron content but are commonly rich in zinc (20%) and lead (12%), and have high concentrations of silver (1.1%, or 2,304 grams/t). In general, the bulk composition of seafloor sulphide deposits in various tectonic settings is a consequence of the nature of the volcanic source rocks from which the metals are leached.

High concentrations of gold have recently been found in sulphide samples from back-arc spreading centres, whereas the average gold content for deposits at mid-ocean ridges is only 1.2 g/t (1,259 samples). Sulphides from the Lau back-arc basin have gold content of up to 29 g/t with an average of 2.8 g/t (103 samples). In the Okinawa Trough, gold-rich sulphide deposits with up to 14 g/t of gold (average 3.1 g/t, 40 samples) occur in a back-arc rift within continental crust. Preliminary analyses of sulphides in the Eastern Manus Basin reveal 15 g/t with a maximum of 55 g/t gold (26 samples). High gold content up to 21 g/t has been found in barite chimneys in the Woodlark Basin. The most gold-rich seafloor deposit found to date is located at Conical Seamount in the territorial waters of Papua New Guinea, close to Lihir Island. Maximum gold concentrations in samples collected from the summit plateau of this seamount (2.8 km basal diameter at 1,600 m water depth, summit at 1,050 m) range up to 230 g/t with an average of 26 g/t (40 samples), which is about 10 times the average value for economically-mineable gold deposits on land.

Tonnage Estimates

Estimates for several deposits on the mid-ocean ridges suggest a size between 1 million and 100 million tonnes. However, gauging the continuity of sulphide outcrops is difficult and little is usually known about the thickness of the deposits. By far the largest deposits are found on failed and heavily-sedimented but still hydrothermally-active oceanic ridges. Drilling carried out by the international Ocean Drilling Program at the sediment-covered Middle Valley deposit on the northern Juan de Fuca Ridge off the northwestern United States has indicated about 8-9 million tonnes of sulphide ore. Drilling 125 m into the active Trans-Atlantic Geotraverse (TAG) hydrothermal mound, located at 3,650 m water depth on the Mid-Atlantic Ridge at 26°N, indicated about 2.7 million tonnes of sulphide ore above the seafloor and approximately 1.2 million t in the underlying deposit, which geologists call the stockwork. Massive sulphide mines as large as Kidd Creek in Canada (135 million t) or Neves Corvo in Portugal (262 million t) have yet to be discovered at the seafloor.

The largest known marine sulphide deposit is the Atlantis II Deep in the Red Sea, which was discovered more than 10 years before the first black smoker at the East Pacific Rise. The Atlantis II Deep mineralization consists largely of metalliferous muds rather than massive sulphides. A detailed evaluation of the 40-km² deposit has indicated 94 million tonnes of dry ore with 2.0% zinc, 0.5% copper, 39 g/t silver and 0.5 g/t gold, for a precious metal content totalling roughly 4,000 t of silver and 50 t of gold. A pilot-mining test at 2,000 m depth has shown that this deposit can be successfully mined.

Resource Potential



Cross-section of a sulphide chimney (Peter Herzig)

Marine mining appears to be feasible under certain conditions, ideally including (1) high base-metal and/or gold grades, (2) site location not too far from land, and (3) shallow water depth not significantly exceeding 2,000 m (although the technology exists for mining in deeper water). Under these circumstances, massive sulphide mining can be economically attractive, considering that the entire mining system is portable and can be moved from site to site. An investment in mining systems and ships would thus not be tied to a single location as is the case on land, where a typical mine development in a remote area including all infrastructure requires a substantial initial investment.

Seafloor massive sulphide mining will likely focus on relatively small areas of the seafloor and largely be restricted to the surface (strip mining) and shallow subsurface (open cast mining) to recover sulphide mounds and chimney fields at the seafloor and replacement ore bodies in the stockwork zone just below it.

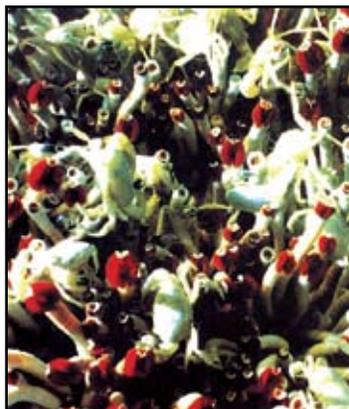
Research, Exploration and Future Mining

Scientific research on polymetallic sulphide deposits and their associated ecosystems is being carried out by academic and governmental institutions worldwide. More recently, private sector mining companies have developed an interest in underwater polymetallic sulphide deposits in exclusive economic zones. Exploration requires sophisticated, multipurpose research vessels using advanced technologies such as deep-sea mapping equipment, manned submersibles or remotely-operated vehicles, photographic and video systems, and sampling and drilling devices. Leading countries in this field are Australia, Canada, France, Germany, Japan, Russian Federation, United Kingdom and the United States. Italy and Portugal have also developed research programmes.

The first commercial operator to explore the seafloor for polymetallic sulphide deposits is Nautilus Minerals, which has commenced exploration in an area roughly the size of the United Kingdom in the exclusive economic zones of Papua New Guinea, Fiji and Tonga and expects to go into commercial production in 2010. Although mining systems have not yet been fully tested for sulphide recovery, they are likely to focus on continuous recovery systems using rotating cutter heads, combined with the lifting of the all slurry to the mining vessel transport to a processing plant.

Environment

The hydrothermal vents associated with massive sulphide deposits provide the habitat for a variety of animal life previously unknown to science. Unlike all other life forms on earth, which depend directly or independently on sunlight and photosynthesis for their energy, the vent community thrives in a lightless, hot water bath suffused with hydrogen sulfide, a chemical lethal to most other



Sulphide vent with tube worms

animals. In this environment dwell worms two metres long, living in tubes of their own making, without a digestive system, deriving their energy from microorganisms that oxidize methane and sulphides. Some 500 previously unknown animal species have been discovered around these biologically diverse vent areas.

The uniqueness and fragility of this geographically fragmented ecosystem, and the value it holds for fundamental biological studies of metabolism, evolution and adaptation, will have to

be taken into account in planning for mineral exploration and exploitation. Studies have shown the resilience of existing populations in dealing with the rapid environmental changes of a volcanically active area. This resilience may be due to the presence of a “mother population” capable of recolonizing a disturbed area. If this base population is destroyed by mining, however, the result could be the extinction of rare species.

Many environmental impacts of sulphide mining would be similar to those due to the extraction of polymetallic nodules, including the destruction of surfaces where animals live, their burial under disturbed sediment and chemical changes due to the suspension of a particulate plume in the bottom water. On the other hand, the high density of sulphide particles would cause immediate redeposition of any sulphide debris produced by mining equipment. Due to the large surface exposed to seawater, some of the liberated sulphide debris would oxidize in a way similar to the oxidation of inactive massive sulphides in many seafloor deposits. Acid mine drainage, which usually causes significant environmental problems in land-based sulphide mines, would be of little concern at the seafloor due to the diluting effect of the surrounding seawater. Moreover, a significant sediment cover is not usually present at most seafloor sulphide deposits. Consequently, mining of selected deposits, particularly inactive ones not inhabited by any kind of vent fauna, is feasible and may not create a larger environmental impact than the construction of a conventional harbour facility.

Future Regulations

Since 2001, the International Seabed Authority has been examining issues concerning the future regulation of prospecting and exploration for polymetallic sulphides and cobalt-rich crusts in the deep ocean beyond national jurisdiction. The topic had been brought to the Authority by the Russian Federation in 1998 but was first discussed in substance in 2002 by the 36-member Council of the Authority. A partial set of model clauses was prepared by the Secretariat, taking account of comments by participants in a scientific workshop on the topic held by the Authority, which placed special emphasis on the need to protect the affected ecosystems from any adverse effects due to exploration and eventual mining. Since then, the Authority has convened a number of seminars and technical working groups to consider specific aspects of the future regulatory system.

The questions raised in relation to these new categories of resources are highly technical and politically sensitive. In contrast to polymetallic nodules, which are relatively well known and studied, crusts and sulphides occur in more concentrated areas, are more unevenly distributed and vary more in metal content from place to place. Data and information to enable the Authority to determine the appropriate size and configuration of areas for exploration is lacking. The parallel mining system envisaged by the Law of the Sea Convention, in which seabed areas allocated to prospective miners are split evenly between those contractors and the Authority, was devised to deal with nodules, which are scattered over broad seabed areas that can be divided up more equitably. One suggested solution is that, rather than exploiting areas of its own, the Authority might enter into joint ventures with future contractors.

In 2006, the Council of the Authority took a decision to proceed, as a matter of priority, with the development of draft regulations for prospecting and exploration for polymetallic sulphides, whilst referring the issue of regulating exploration for cobalt-rich crusts to the Legal and Technical Commission for further study. In 2007, the Council undertook a first reading of a set of draft regulations relating to polymetallic sulphides and will continue this work in 2008. Amongst the core issues to be discussed are the size of the area to be allocated for exploration, the fee system to be applied and the system for site allocation between contractors.